

# **OHIO UNIVERSITY**

***School of Electrical Engineering & Computer Science***

## **MLS Band Sounding Measurements: Channel Characterization for Mobile and Fixed Airport Surface Communications**

**ACAST Workshop  
16 August 2005**

**David W. Matolak, Indranil Sen**

School of EECS and Avionics Engineering Center  
Ohio University  
Athens, OH 45701  
phone: 740.593.1241  
fax: 740.593.0007  
email: matolak@ohiou.edu, is809902@ohio.edu

**Rafael Apaza**

Federal Aviation Administration  
Aviation Research Office  
Belleville, MI  
phone: (734) 487-7327  
fax: (734) 487-7428  
email: rafael.Apaza@faa.gov

# Outline

- Introduction
  - Motivation and Band Selection
  - Importance of channel characterization
- Measurement Coordination
- Channel characterization overview
  - Method, sounder, example photos
  - Example results: mobile measurements
  - Comparison highlights (MIA and CLE)
  - Point-to-Point measurement results
- Summary & future work



# Introduction

- Motivation
  - Civilian aviation anticipates both a near and long-term need for new communications capabilities
    - VHF spectral congestion
    - New services desired, both for mobile and “fixed” services
- Band selection
  - Easiest to quickly deploy system in “clean” spectrum
  - Deployment of new systems to “protect” reserved aeronautical spectrum (“use it or lose it”)
  - Both these points apply to the MLS extension band, 5.091-5.15 GHz, which is not widely used in many regions



# Introduction (2)

- Importance of channel characterization
  - Simply: if you don't know your channel, system performance will be suboptimal, possibly very poor, with
    - irreducible channel error rate that can preclude reliable message transfer
    - spatial coverage “holes” where communication is not possible
    - severely limited data carrying capacity which would require costly system additions to circumvent
  - Very little work done for MLS band channel
    - Zero wideband experimental work for this band around airport surfaces



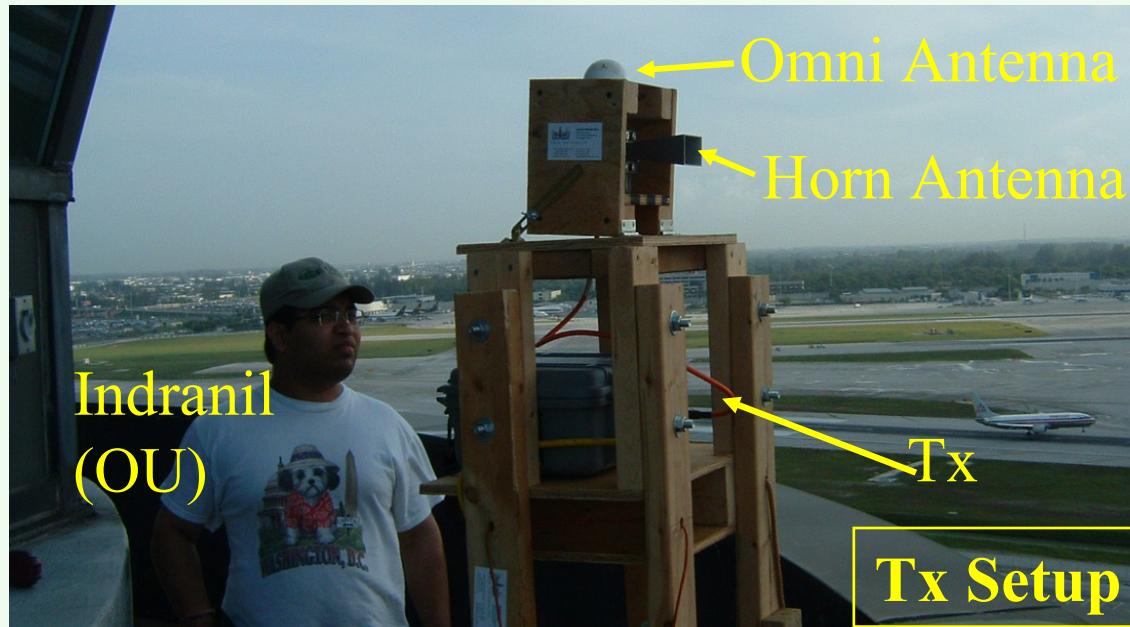
# Measurement Coordination

- Miami International Airport (MIA) is the 12<sup>th</sup> busiest airport in the US; Cleveland Hopkins (CLE) is one of the 50<sup>th</sup> busiest
- Access to airport movement area has become more complicated in the post 9/11 era
  - Strict security procedures must be followed to gain access to the airport surface area—requires careful coordination with airport management
- Principle objective when planning a measurement activity is to minimize the impact to airport operations



# Measurement Coordination (2)

- Prior to any measurements, FAA Spectrum Office conducted an RFI study (clean!)
- Obtained a Special Temporary Authorization to transmit at the test frequency

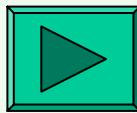


Selected “cat walk” at (old) ATCT sub-junction level for Tx

- Good field of view
- Access to AC power

# Measurement Coordination (3)

- Updated CLE measurement plan and for MIA, refined
  - Data recording locations
  - Procedural approach
  - Airport ingress and egress requirements, driving rules
  - # personnel required to complete measurements
- Desired measurement locations evaluated with FAA for
  - accessibility
  - time of day
  - aircraft traffic activity
  - measurement execution
- Final measurement plan evaluated and approved by FAA



# Measurement Coordination (4)

- MIAMI aerial view, with numbered measurement locations



- Covered
- Taxiways
- Gates
- Cargo areas
- Access roads
- Both LOS and NLOS sites
- Also conducted mobile tests w/Tx at P2

# Channel Characterization Overview

- Thorough and accurate channel characterization requires combination of 3 inter-related components:
  - *Analysis*: validate against theory, guide measurements
  - *Simulations*: create models for consistent evaluation of comparative system designs
  - *Measurements*: data to build models, affirm theory, help classify, and identify unforeseen conditions
- Analytical and measurement results we obtain will be directly usable by engineers evaluating and/or designing communication systems for this application

$$h(\tau; t) = \sum_{k=0}^{N-1} \alpha_k(t) \exp\{j[\omega_{D,k}(t - \tau_k(t)) - \omega_c(t)\tau_k(t)]\} \delta[t - \tau_k(t)]$$

# Airport Surface Environment

- Airport movement area is a dynamic environment
  - airline ramp activities such as baggage handling, fueling, catering taking place throughout the day
  - aircraft also taxiing, pushing and pulling out of gates
  - airport security vehicles, other ground vehicles moving about
- **Airport surface area classification**
  - **LOS-O: Open areas, e.g., runways, some taxiways**
  - **NLOS-S: mostly NLOS w/dominant Specular component plus low energy multipath components, e.g., near terminals**
  - **NLOS: obstructed LOS, largest DS, e.g., near gates**
- Aircraft inhabit all three regions—non-stationary channel, in contrast to most terrestrial models
- Large buildings present persistent, long-delay multipath, also in contrast to most terrestrial models

# Channel Sounder

- For sounding, we have purchased and employed a wideband channel sounder with adjustable center frequency, transmit power, and bandwidth



- Modified version of Berkeley Varitronics Inc. “Raptor” model, with several upgrades
  - faster data output rate
  - wider bandwidth
  - increased output power
- Multiple antenna types



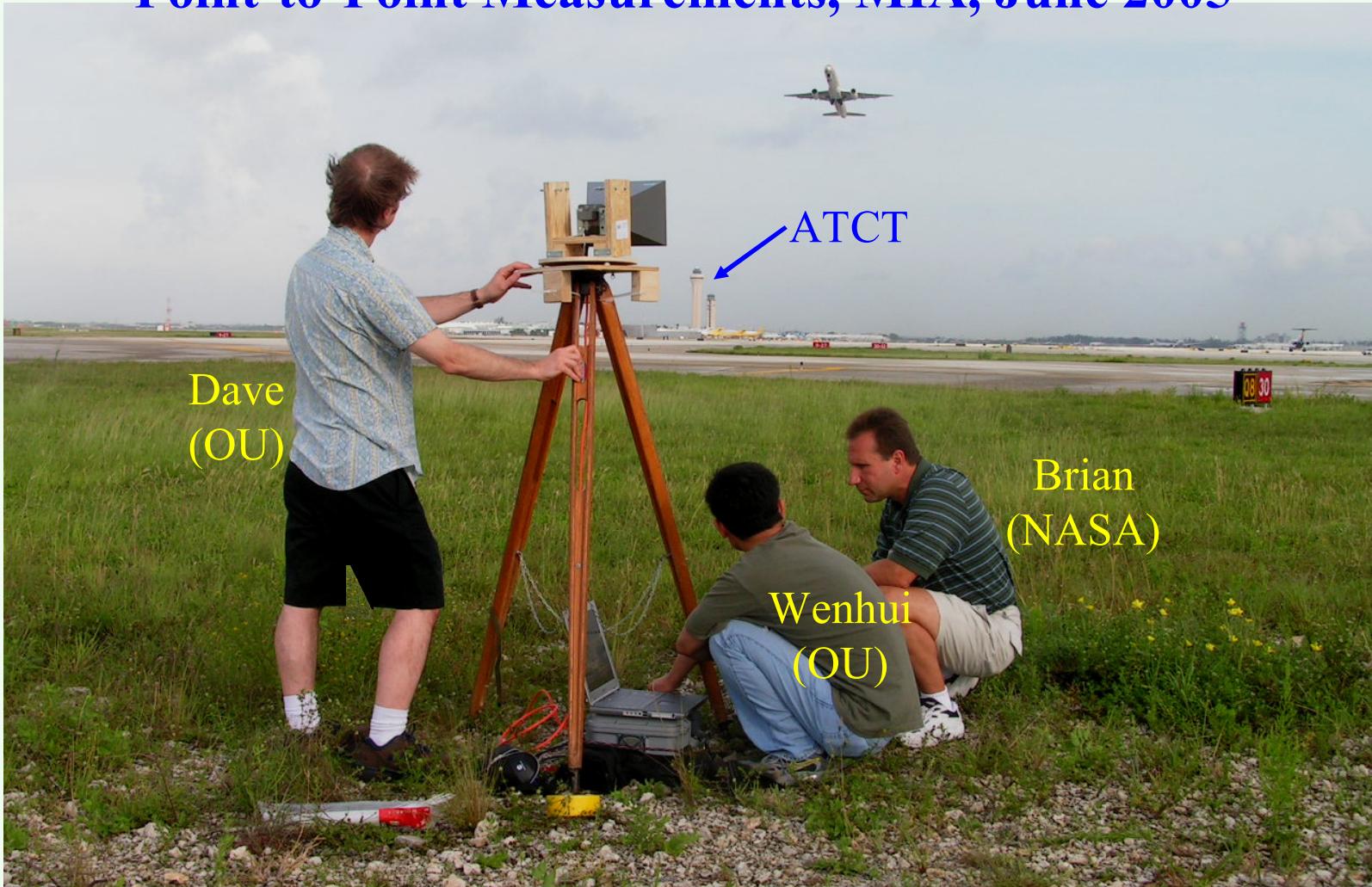
Ohio University

# Measurements: Example Photos (1)



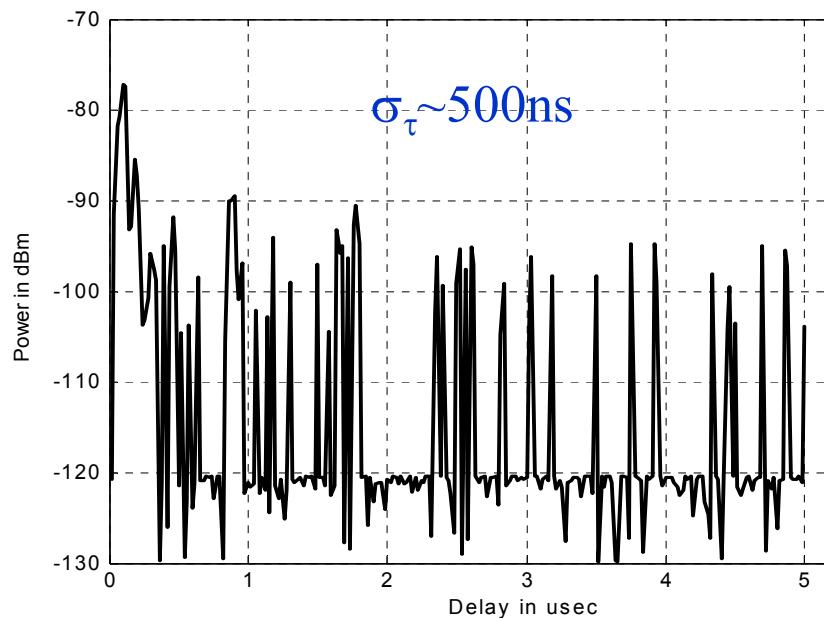
# Measurements: Example Photos (2)

## Point-to-Point Measurements, MIA, June 2005



# Example Results

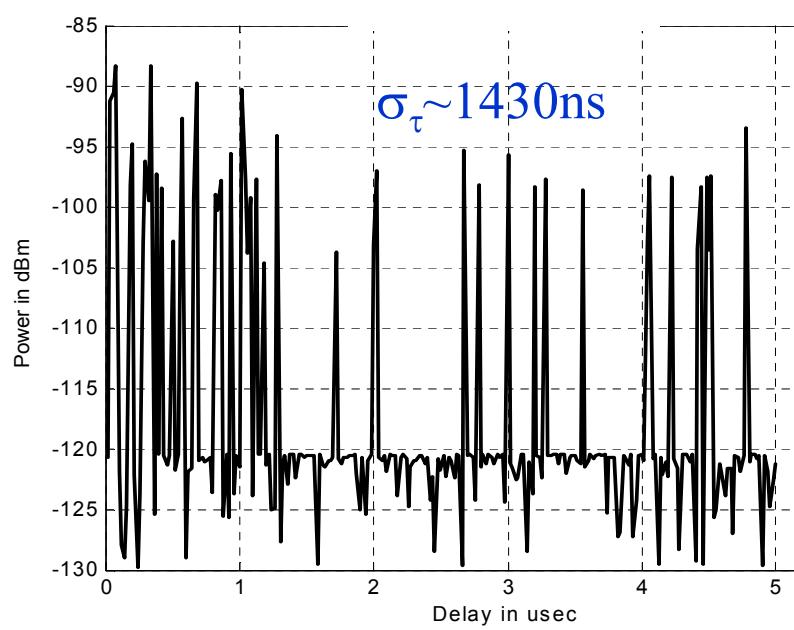
- Power delay profiles—PDPs (received power vs. delay), after noise thresholding



**CLE, NLOS-S case**

Significant multipath ( $\sim 9$  dB) up to  
 $3T_c$  (0.06  $\mu$ sec) + numerous  
weaker components

Ohio University

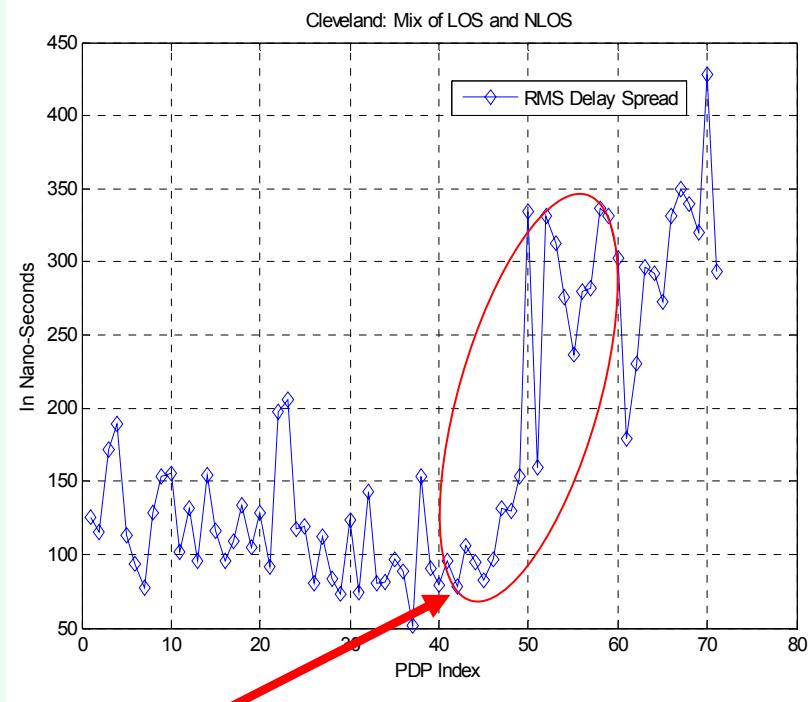


**MIA, NLOS case**

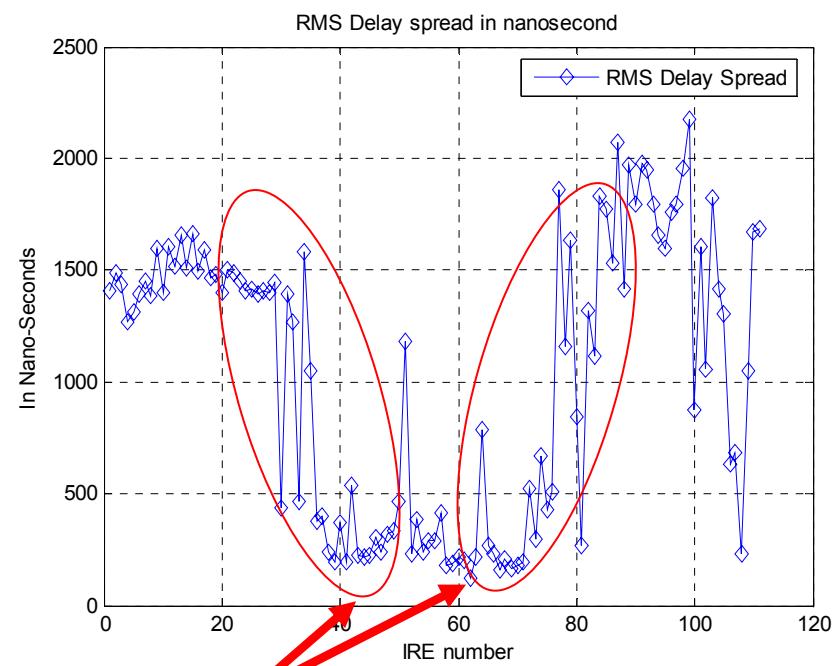
Significant multipath ( $\sim 0$  dB)  
up to  $15T_c$  (0.3  $\mu$ sec)

# Example Results (2)

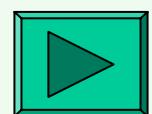
- Useful statistic is RMS delay spread (DS)
- Plots of RMS-DS vs. profile index (time)



**CLE:** Single transition  
from LOS to NLOS



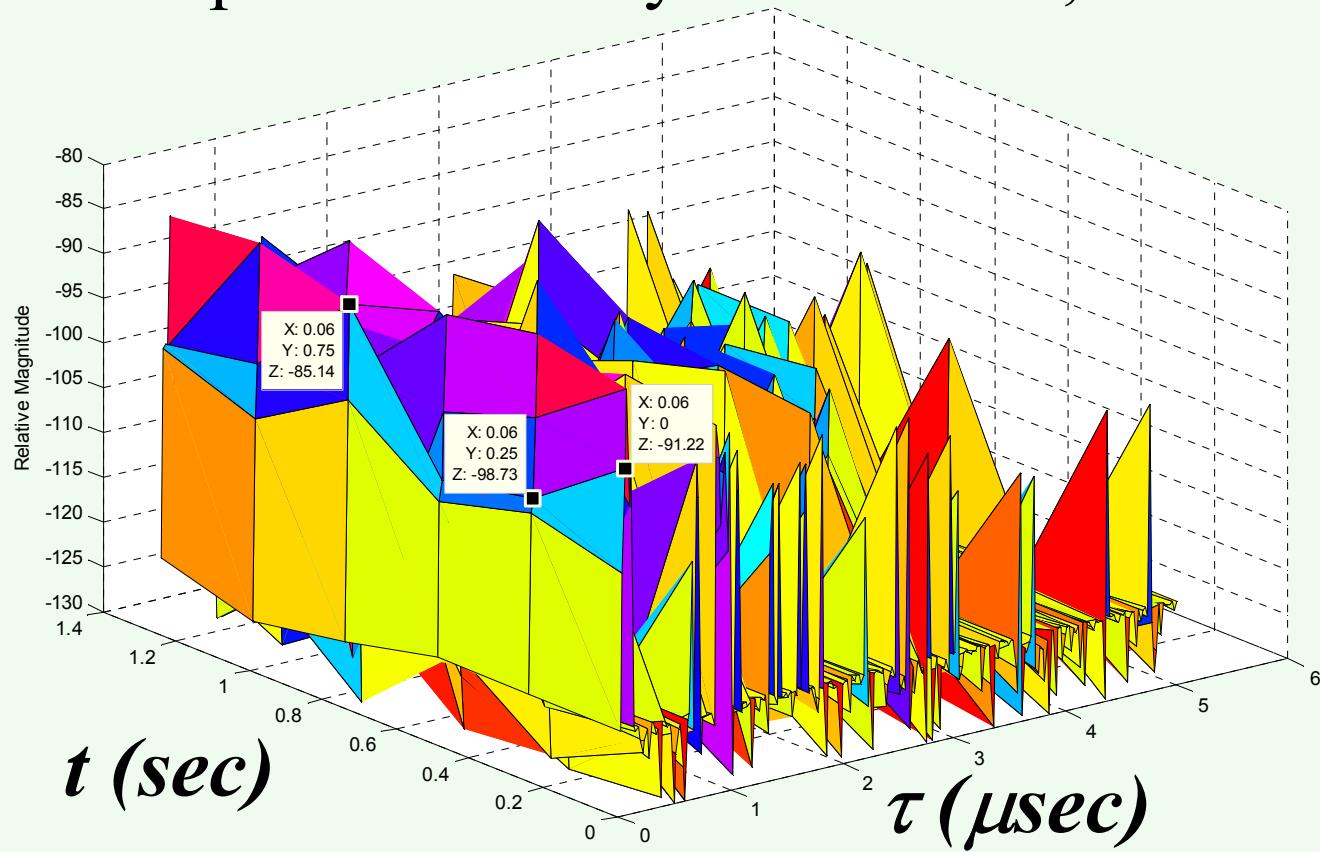
**MIA:** Multiple transitions  
to/from NLOS/LOS/NLOS



Ohio University

# Example Results (3)

- MIA PDP: power vs. delay and vs. time, NLOS



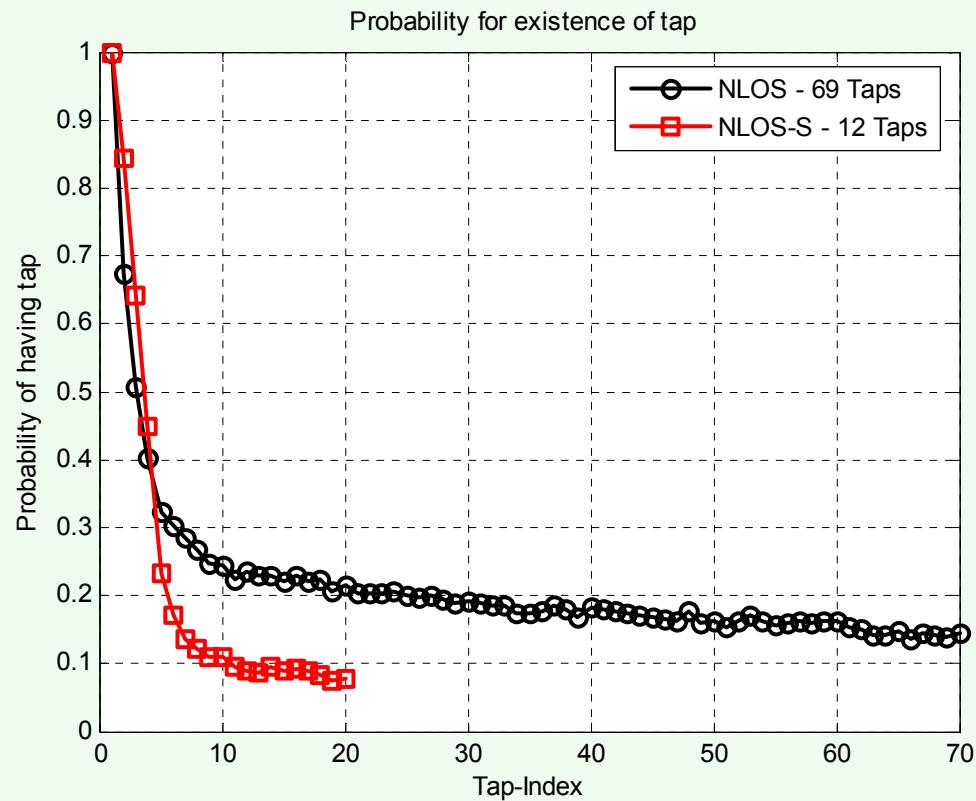
# MIA: Two Regions Measured

- NLOS-Specular (NLOS-S)
  - Majority of airport surface area (approx 65% of time)
  - Mostly NLOS conditions with dominant specular component and a number of low energy multipath components
- NLOS
  - Obstructed or grazing specular component, and significant number of high-relative-energy multipath components

MIA Statistics					CLE $\sigma_\tau$ Stats	
$\sigma_\tau$ Statistic	NLOS-S (nsec)	BW <sub>c</sub> (MHz)	NLOS (nsec)	BW <sub>c</sub> (MHz)	LOSO (nsec)	MR (nsec)
<b>Max</b>	1000	1	2394	0.417	395	2306
<b>Min</b>	32.8	30.5	1001	0.995	49.5	401
<b>Mean</b>	380	2.6	1382	0.723	311	763

# Example Modeling Result, MIA

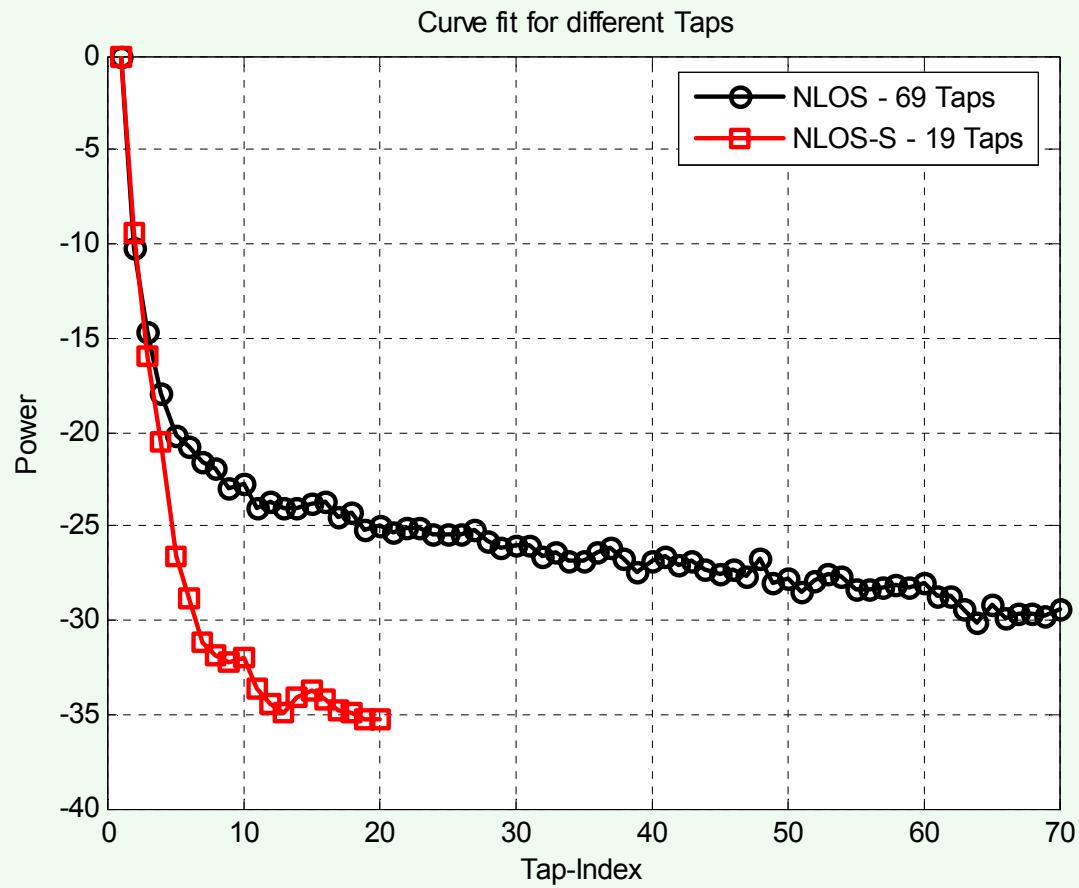
- Tap probability of occurrence (fraction of time)
- Threshold = 20 dB from main tap



- NLOS-S
  - Number of taps = 19
- NLOS
  - Number of taps = 69

# Example Modeling Result (2)

- Average power versus tap index

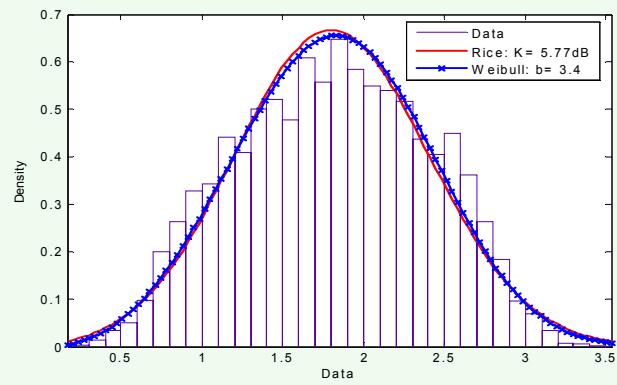


- NLOS-S
  - Number of taps = 19
  - 4 taps total within ~20 dB of main tap
- NLOS
  - Number of taps=69
  - 5 taps total within ~20 dB of main tap

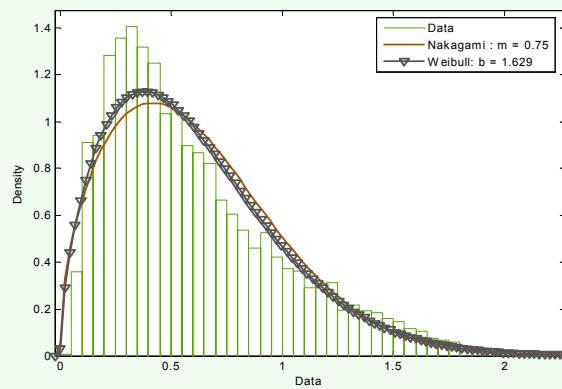
# Example Modeling Result (3)

- Amplitude distribution, MIA

Tap #1 (Specular)

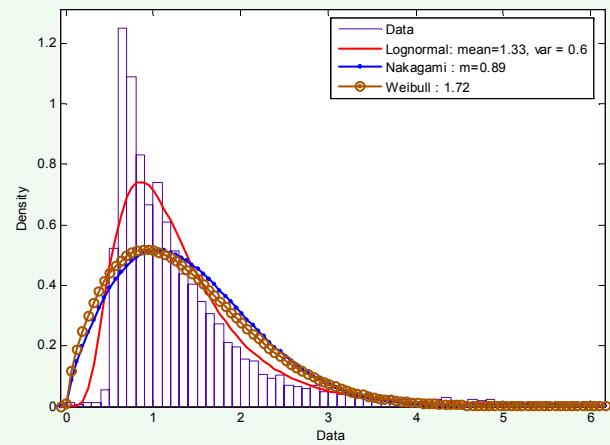


Tap #2

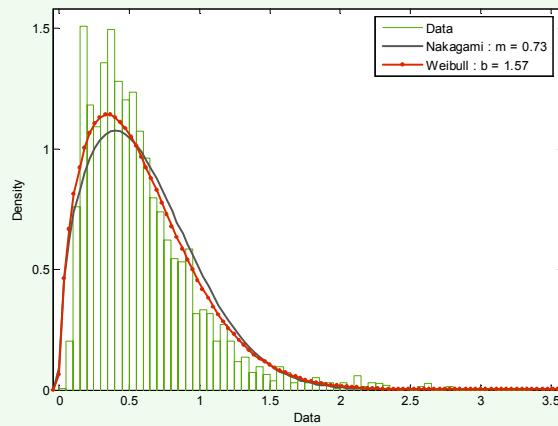


NLOS-S

Tap #1



Tap #2



NLOS

# Airport Comparisons

- MIA= LARGE airport; CLE= MEDIUM airport
- Some similarities in channel characteristics
  - Both have 3 regions: LOS-Open, NLOS-S, and NLOS
  - Both have correlated scattering, in all regions
  - Amplitude statistics for some taps worse than Rayleigh
- Significant differences in channel characteristics
  - Reflectors much bigger in MIA (larger planes and larger buildings), yielding persistent, strong, long-delay multipath
    - Generally larger delay spreads in MIA
  - RMS-DS shows multiple transitions within single data set

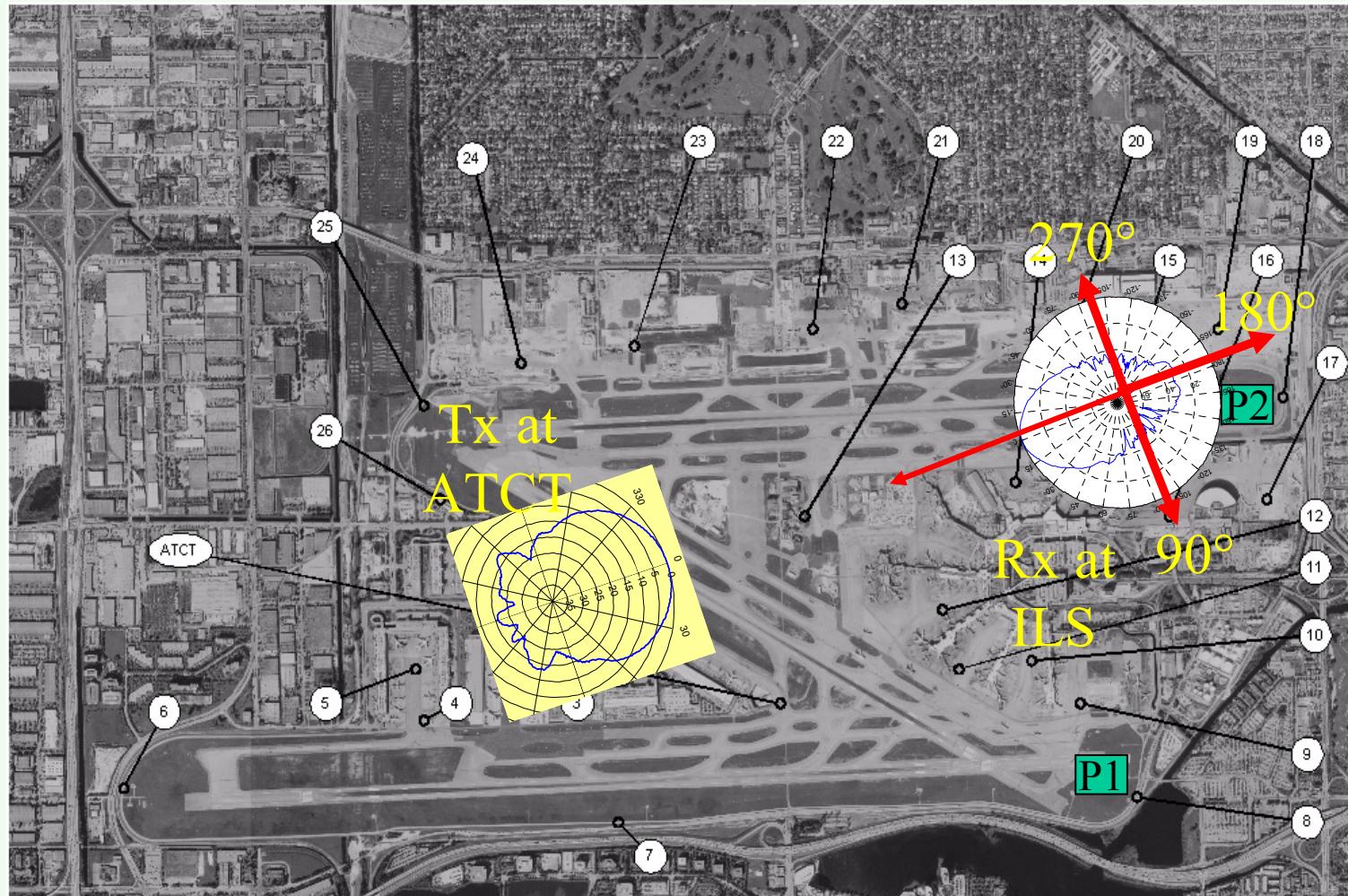


# Point-to-Point Measurements

- From ATCT to ground sites
- Envisioned use of ground sites
  - Data transfer from sensors to ATCT
  - Relay of information from mobile platforms to/from ATCT
- Characterized received power and delay spread vs. azimuth angle

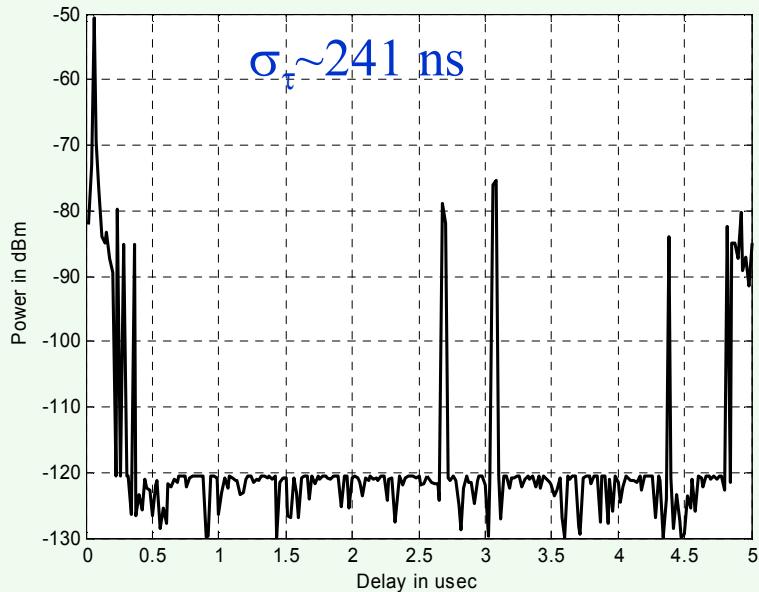


# ILS Site Orientations



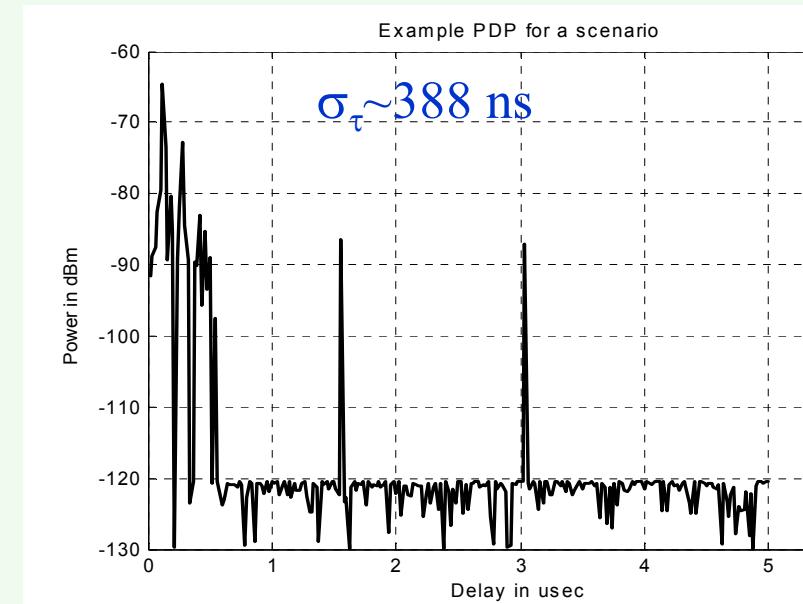
# Example Results: ILS Site

- Power delay profile, after noise thresholding



$0^\circ$  (Boresight)

- Multipath ( $\sim -10$  dB) from ground reflection
- All other multipath more than 25 dB down from LOS signal

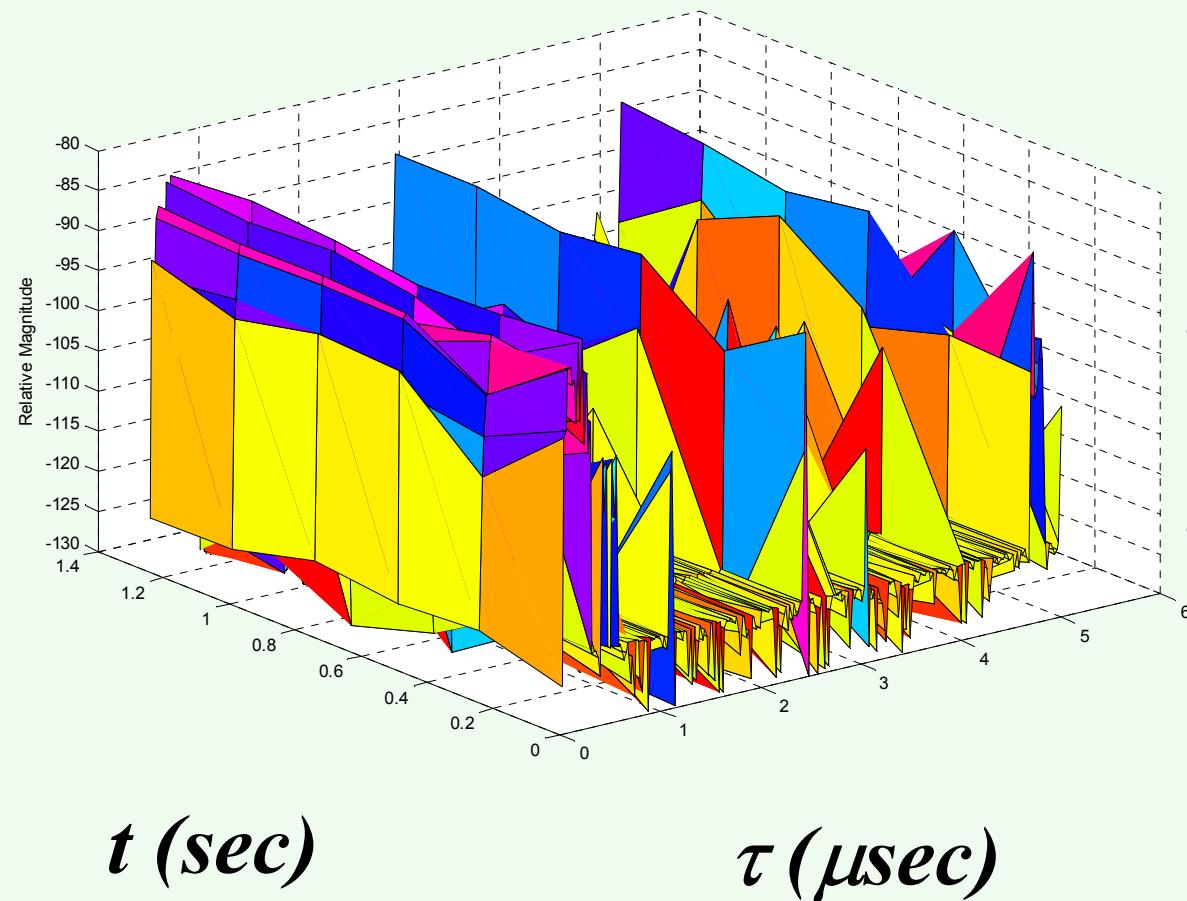


$15^\circ$  Orientation

- Multipath ( $\sim -8$  dB) at  $\sim 0.3 \mu\text{sec}$
- All other multipath more than 20 dB down from LOS signal

# Example Results (2)

- PDP: power vs. delay and vs. time

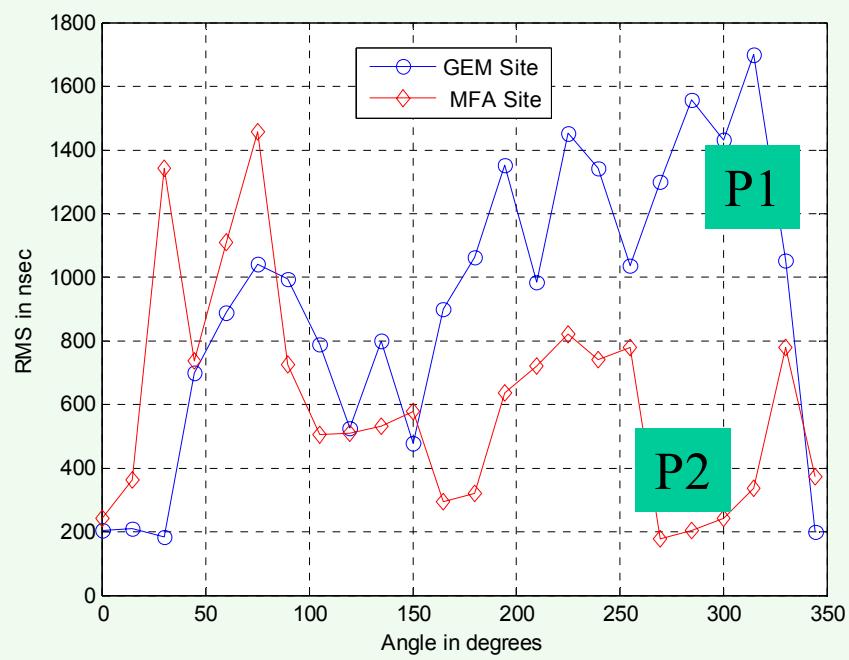


- 105° Orientation
- Direct signal and stable multipath at 0.3, 2.5 and 4  $\mu$ sec
  - Stable multipath from large buildings

# Example Results (3)



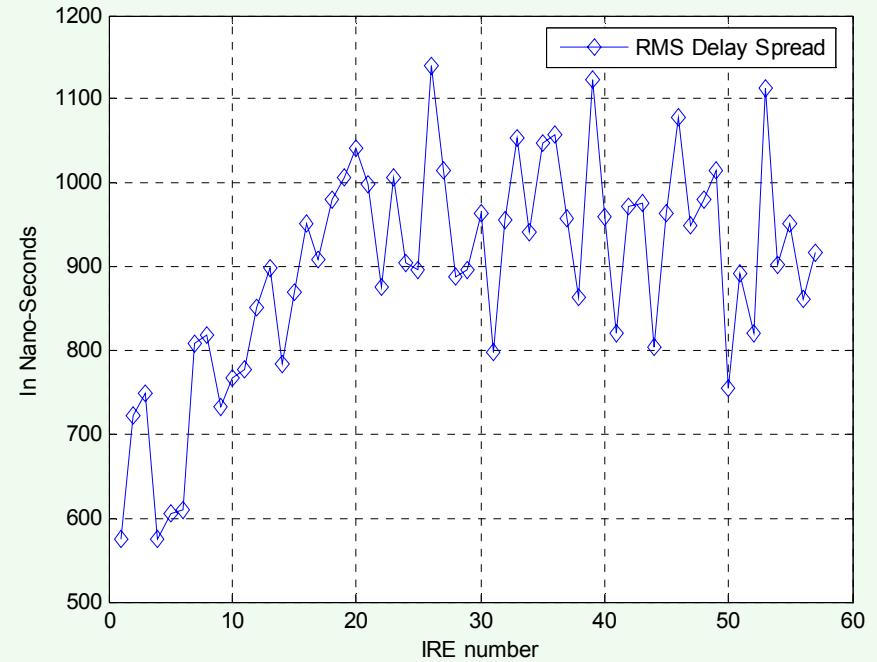
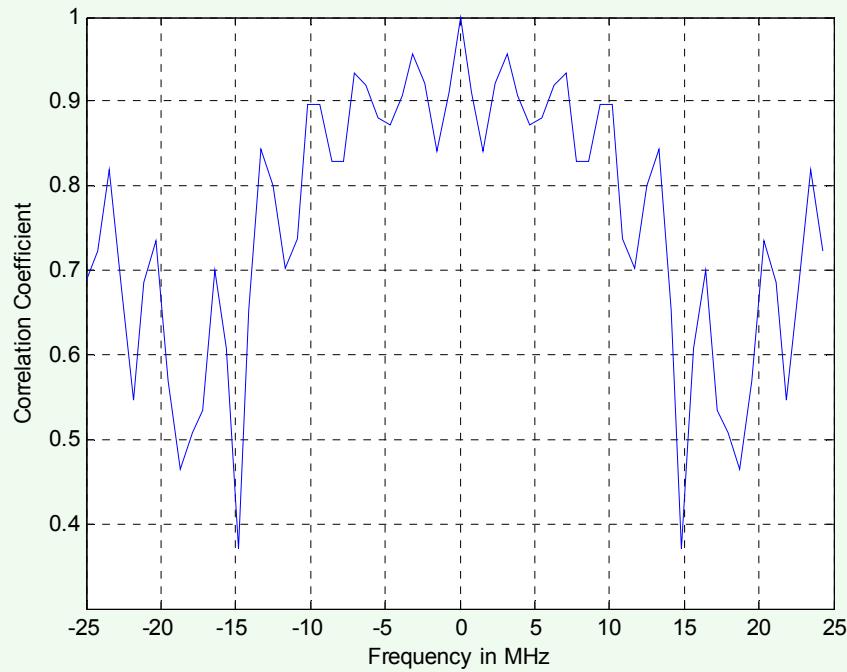
Received power vs. azimuth angle, ILS site (P2)



RMS-DS vs. azimuth angle

# Example Result (4)

- FCE and RMS-DS vs. time, 165° GEM (P1)
- PDP can vary in time with mobile scatterers (vehicles, people)



# Point to Point Link Summary

- Both CLE & MIA measurements show MLS band use feasible
  - Link closure easy with typical components
  - Lower channel dispersion (than mobile settings)
  - Larger coherence BW (than mobile)
  - Potential for angular (spatial) diversity for improved security and performance
  - Measurements of received power and RMS-DS vs. azimuth useful for siting (e.g., help determine where NOT to locate relay stations)



# Summary

- Provided update on characterization of the 5 GHz MLS “extension” band channel
  - Need for effort from the point of view of efficient communication link design, and band protection
- Recent measurement campaigns at CLE and MIA airports described, including
  - Coordination w/ local authorities required for successful tests
  - Short description of equipment, measurement process
  - Example measured results
  - Example modeling results
  - Results for point-to-point links

# Future Work

- Gather additional measurement data at one (or two) more large airports
  - JFK, 28-31, Aug 2005
  - Detroit? Fall 2005?
- Completion of data processing
- Completion of channel modeling for
  - Mobile settings
  - Point to point settings
  - “Relay” settings

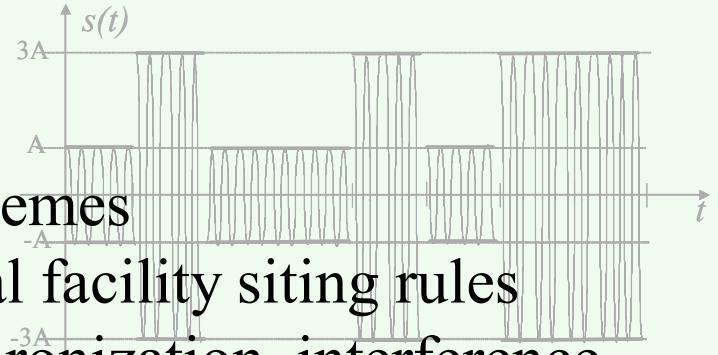
# “Back Up” Slides



Ohio University

# Impact of Channel Characteristics

- Channel characteristics affect
  - modulation(s)
  - forward error correction coding schemes
  - antenna characteristics, and physical facility siting rules
  - receiver processing methods (synchronization, interference suppression, combining, etc., all generally adaptive)
  - power spectrum and bandwidths
  - attainable data rates and latencies, message block sizes
  - adaptation algorithms for allocating resources in T/F/S domains
  - authentication and user ingress/egress latencies
  - duplexing and multiplexing methods
  - security measures and performance (against eavesdropping, jamming, spoofing, etc.)

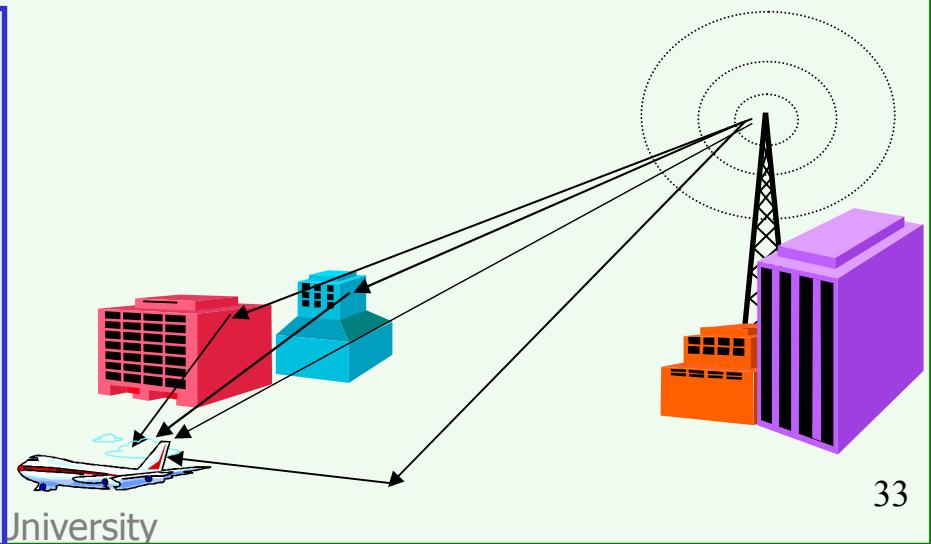


# Channel Characterization Method

- “Sounding” = transmission and subsequent reception of a test signal, from which we can infer channel characteristics: the impulse response
- Common test signal is a direct-sequence spread spectrum signal, whose known correlation properties can be exploited to estimate channel’s impulse response

*What is the channel?*

A wireless channel is the (set of) transmission path(s) taken by an electromagnetic signal from transmitter to receiver. The mobile channel is the wireless channel with at least one platform (Tx or Rx) in motion.



# Regulatory Issues

- Through industry support functions such as I-CNS 2004, ACAST 2004, NASA has identified protection of the 5000-5150 MHz band for aviation use as one of the top priorities for ACAST
  - Emphasis on the MLS extension band 5091-5150 MHz
    - First, GPS navigation and WAAS/LAAS enhancements circumventing need for MLS deployments, leaving much of the MLS band either quiet or underutilized
    - Second, spectrum at 5 GHz presents enormous potential for revenue to short range, wideband wireless networking OEMs (e.g., 802.11)
    - Third, spectrum auctions in or near this band present potential revenue streams for the federal government
  - Combination of these factors has heightened need to justify the continued use of this spectrum for aviation purposes

# Regulatory Issues (2)

- It is NASA's intent to demonstrate, through ACAST, the applicability of this band for wideband surface area signaling, and how this usage may alleviate some of the congested VHF voice bands for ATC
- The first step in this effort is proper characterization of the MLS radio channel
- Radio Communication group of the International Telecommunication Union (ITU-R) holds a World Radio Conference (WRC) every 3-4 years
  - Member nations discuss and decide upon the global use of radio spectrum at these conferences

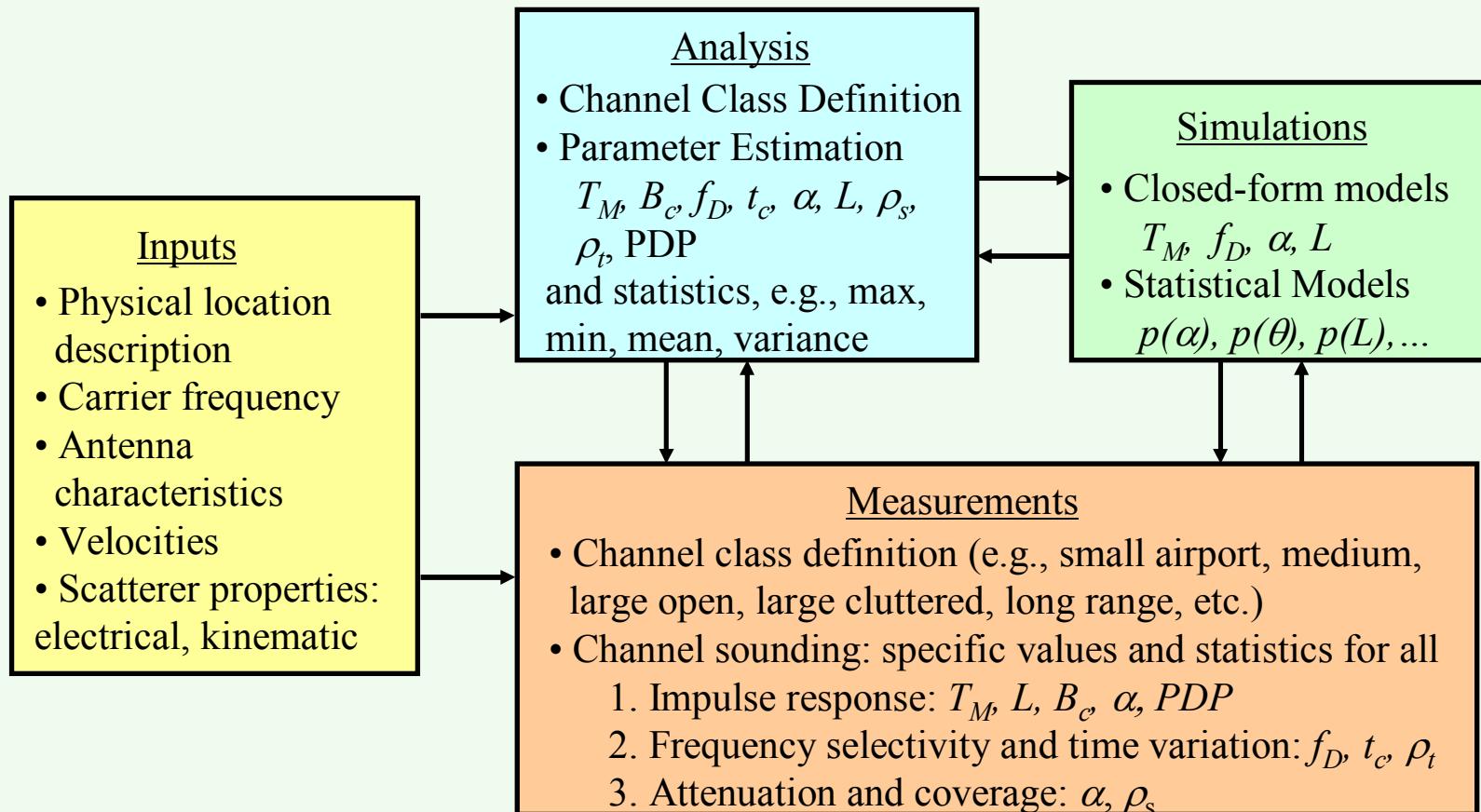
# Regulatory Issues Detail

- On agenda of WRC-2007 is use of aviation spectrum:

“To consider allocations for the aeronautical mobile (R) service in parts of the bands between 108 MHz to 6 GHz, and to study current frequency allocations that will support the modernization of civil aviation telecommunication systems.”
- This agenda item affords opportunity to have areas of spectrum between 108 MHz to 6 GHz characterized for aeronautical mobile route services (AM(R)S
  - Results of channel characterization being presented to domestic and international governing bodies so that there is a sound engineering argument for use of this band for wideband signaling on the airport surface, and that this band may be included in regards to Agenda Item 1.6. It is intended that this effort support inclusion of MLS band as an integral piece of modernization of civil aviation communication systems

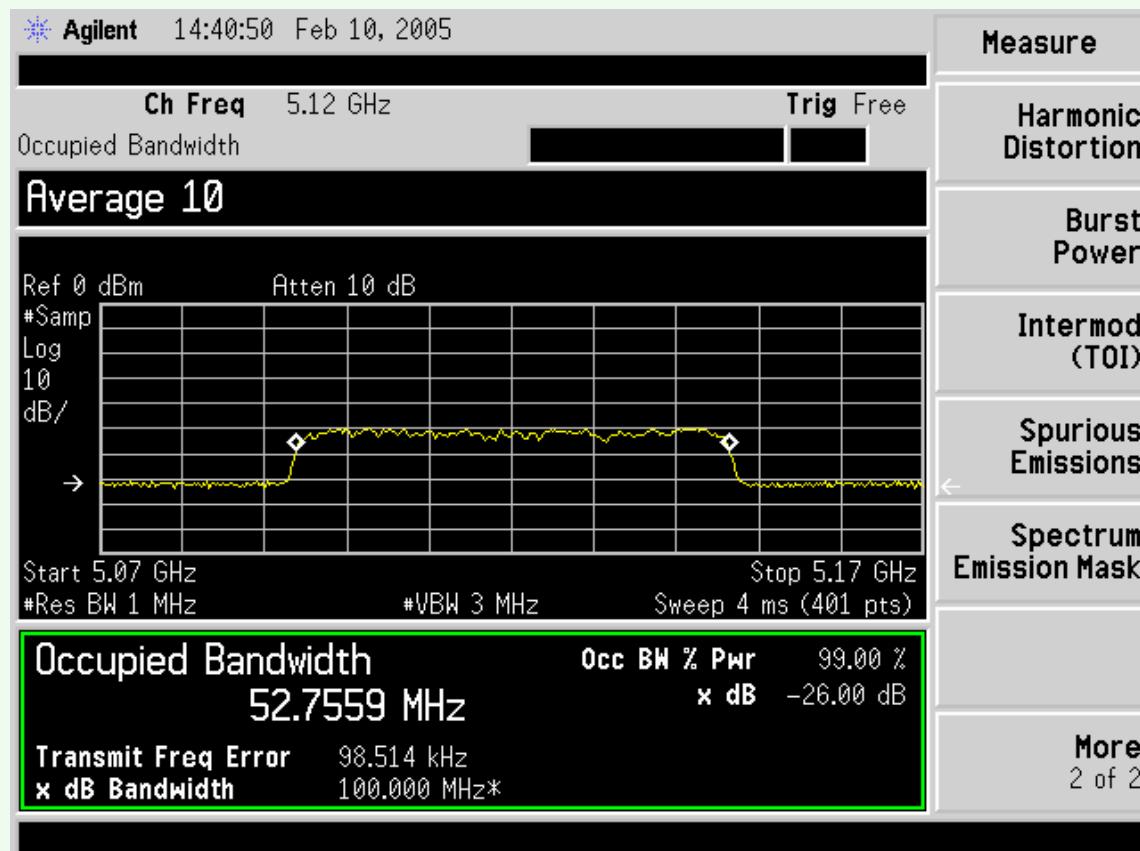
# Channel Characterization Plan

- Today's focus on measurements and analysis



# Channel Sounder Spectrum

- Transmitted signal measured power spectrum



- Chip rate 50 Mcps
- $f_c=5.12 \text{ GHz}$
- Span=100 MHz
- 99% power BW equal to 52.76 MHz

# CLE Pt-to-Pt Channel Statistics

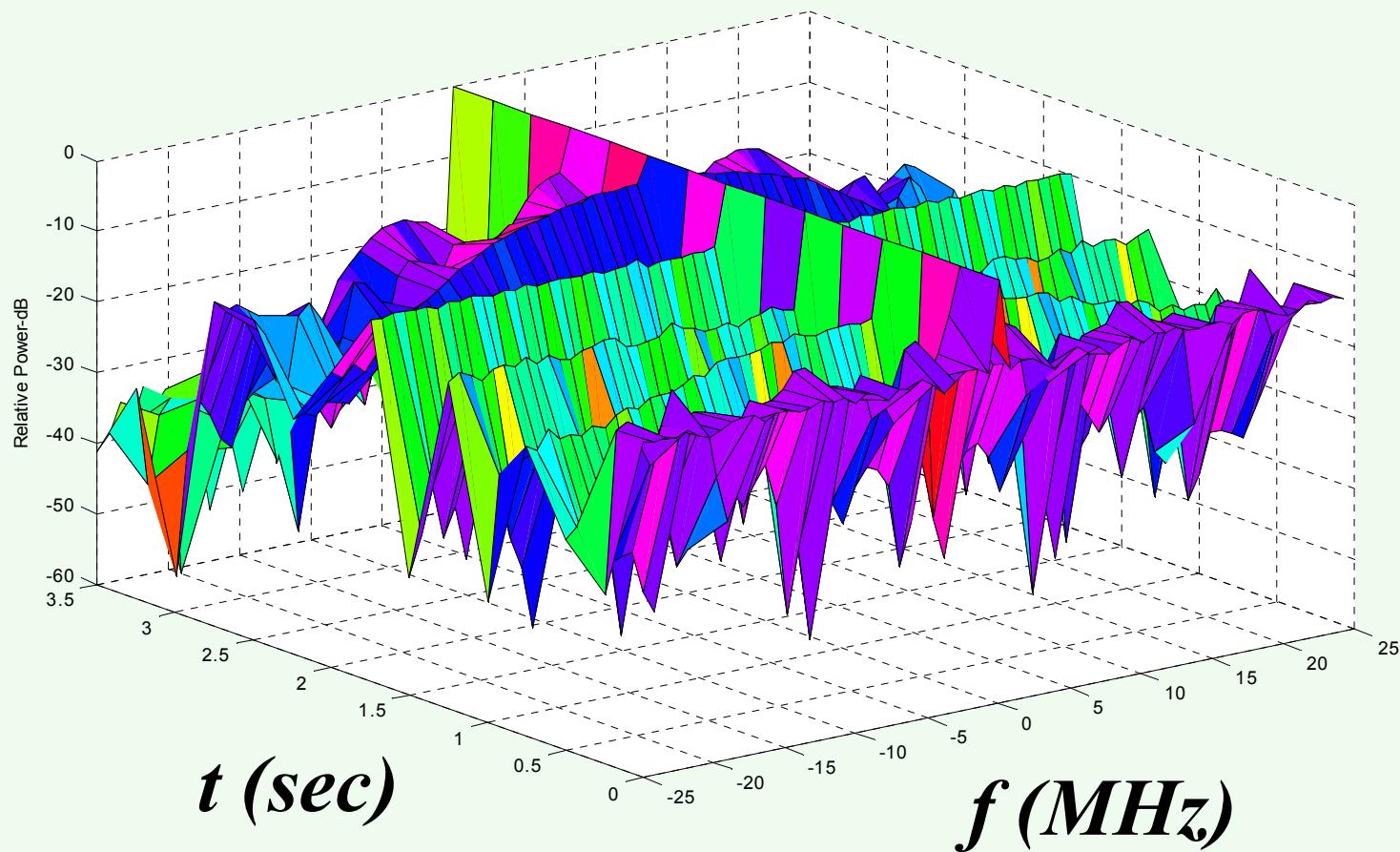
## RMS-DS and Coherence Bandwidth Three Point-to-Point Settings

Location	RMS Delay Spread for 4 Angular Orientations (0° is “boresight”) (nanoseconds)				Frequency Correlation Estimate at Correlation of [0.8, 0.5, 0.3] for 4 Angular Orientations (MHz)			
	0°	90°	180°	270°	0°	90°	180°	270°
1 (1.4 km)	31.8	101	70	273	[2.3, 3.9, 5.4]	[2.3, 4.5, 5.6]	[2, 3.5, 4.5]	[1.5, 4.25, 5]
2 (3.3 km)	48.2	101	170	312	[2, 3.25, 4]	[4, 7.25, 8.5]	[2, 3.5, 4.5]	[1.5, 2.75, 3.2]
3 (1.3 km)	40	294	239	146	[2.2, 3.7, 4.5]	[2, 3.25, 4]	[1.7, 3.2, 4.5]	[1.75, 3.2, 4.2]

Knowing delay spread and frequency correlation as function of angle and time enables selection of signal bandwidth/data rates, siting, diversity, and antenna characteristics

# Example Results, MIA

- Time-varying spectrum  $|H(f,t)|^2$



# Point-to-Point Measurements

- Tx/Rx Antenna Characteristics
  - Gain ~8.5/17 dB
  - Azimuth
    - 3 dB beamwidth ~60/30°
    - 10 dB beamwidth ~ 100/50°
  - Elevation
    - 3 dB beamwidth ~ 60/15°
    - 10 dB beamwidth ~ 120/30°
- RSSI and power delay profile (PDP) measurements taken at 24 angles in azimuth, 15° apart

